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A PERSPECTIVE ON SEAWATER/FRP REINFORCEMENT IN CONCRETE STRUCTURES

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Predictions show that more than half of the world population will lack sufficient freshwater by 2025. Yet, the construction industry uses a considerable amount of freshwater to produce concrete. To save resources of fresh water, using seawater seems to be a valid potential alternative that can replace freshwater for mixing concrete. This paper presents a short review performed on existing literature related to the usage of seawater in concrete structures. As a summary of the work presented: (a) It is noticeable that the current literature, generally, reports little or no negative effect of seawater on the characteristics of plain concrete, both in the short and in the long term; (b) steel corrosion caused by the presence of chloride appears to be the sole reason for not accepting the use of seawater in concrete preparation; (c) Fiber reinforced polymer (FRP) is discussed as a promising alternative to steel for seawater-concrete reinforcement, owing to their light weight, high tensile strength, and adequate corrosion resistance; and (d) A future outlook for using seawater accompanied by FRP reinforcement in concrete structures is discussed in terms of achieving sustainability goals.

Keywords: Water shortage, Mixing with saltwater, Chloride threshold limit, Steel corrosion, FRP-reinforced concrete, Sustainable concrete.

1 INTRODUCTION

Concrete is the most commonly-used construction material worldwide, which is typically produced by mixing cement, freshwater, aggregates, and admixtures (Gambhir 2013). The construction industry uses over a billion tons of potable water every year to produce concrete (Meyer 2009). The usage of reinforced concrete increases all over the world and if the current practices of preparation continue, more and more freshwater supplies, which are critical for the survival of human civilization, will be depleted. In effect, predictions show that more than half of the world population might lack sufficient freshwater by 2025 (Parish *et al.* 2012).

Therefore, it becomes obvious that one of the most significant steps towards sustainability would be reducing, to the extent possible, the unnecessary wasting of freshwater for concrete production. A valid possibility to preserve freshwater in the concrete industry is represented by the use of seawater in concrete. Despite its potential advantages, from the perspective of sustainability goals, the use of seawater in the concrete mix is currently prohibited. In all likelihood, the key reason for prohibiting the use of seawater in reinforced concrete structures is the corrosion of steel reinforcement (Fernandez *et al.* 2016), bearing in mind the high presence of chlorides in seawater. In effect, seawater has an average total salinity of 3.5%, of which 78% is sodium chloride (NaCl) (Antonov *et al.* 2010).

This paper aims to explore the possibilities for using seawater in mixing and curing concrete instead of freshwater, from the view of existing literature. At the outset, the effect of seawater on the mechanical properties of non-reinforced concrete will be discussed. After that, the negative impact of seawater usage on steel-reinforced concrete will be explained. Subsequently, the fiber reinforced polymer (FRP) will be proposed as reinforcement for concrete structures to overcome the corrosion issue associated with steel reinforcement in saltwater-mixed concrete. Finally, a future perspective on a more sustainable concrete using the proposed combination of seawater with non-corrosive reinforcement will be displayed.

2 SEAWATER IN PLAIN CONCRETE

There is a common belief that seawater is improper for use in structural concrete. Nevertheless, there is a number of structures along the coasts of South California and Florida built with seawater concrete (Kaushik and Islam 1995). This can be regarded as an intuitive evidence for the possible use of seawater in the concrete mixture. Moreover, the existing technical literature reports that salt in seawater has no significant negative effects on the characteristics of the hardened concrete, and, if durability problems occur, they are mainly related to the corrosion of steel reinforcement rather than the effect on concrete properties. Starting from the early works, Narver (1964) registered a higher compressive strength for the first month, then, from the third month, the strength had a constant difference of 6% compared to the freshwater concrete. The mixes for the two types of concrete were identical, with the exception of water type. Similarly, Steinour (1960) showed an increase in early strength and then a decrease of 8% to 15% for seawater concrete. However, the research conducted by Griffin and Henry (1964) shows a strength increase not only for early ages but also in the long term. A gain in strength was also reported by Dewar (1963), who has interestingly underlined that the concrete compressive strength increases with the salinity content of the mixing water.

More recently, Mohammed *et al*. (2004) conducted a study on specimens made of different mixtures immersed in a saltwater pool. This environment tried to recreate the tidal zone in the laboratory. The effects of these conditions were studied at different ages. The results showed an increase in the compressive strength for the first five years, followed by a gradual reduction until the tenth year, while at 20 years, the strength approaches the value of the 28-day strength. It was concluded that the presence of seawater in the mixes did not affect the long-term compressive strength. Nishida *et al*. (2013) conducted a comprehensive review on about 85 references published between 1974 and 2013 and dealt with the outcomes of using seawater in the concrete mixture. The aim of that study was to open up the chances for the seawater to be applied as mixing or curing water in concrete based on the analysis of existing literature results. Nishida *et al*. (2013) also stated that more than 50% of the publications cited in their study had promising results for seawater-mixed concrete, especially in the case of using mineral admixture such as blast furnace slag (as illustrated in Figure 1). Furthermore, it was concluded that studies concerning long-term assessments indicated a reasonable prospect of using seawater in the concrete mixture (Nishida *et al.* 2013). Research studies conducted afterward have generally shown a good agreement with these results (Cui *et al.* 2014, Lim *et al.* 2015).

As an attempt to redefine the sustainability of concrete, an intercontinental project, referred to as SEACON, has been launched in 2015 under the leadership of University of Miami. This project aims to illustrate the safe utilization of seawater and salt-contaminated aggregates to achieve a sustainable concrete production when combined with noncorrosive reinforcement. Part of the current results of the project has been revealed in (Khatibmasjedi *et al.* 2016), where three concrete mixtures have been used, namely: (a) Traditional concrete mixture with fresh water and conventional aggregates; (b) Seawater concrete mixture with conventional aggregates; and (c) Seawater concrete mixture with recycled concrete aggregates. The concrete specimens were subjected to three types of exposure, which are: (i) ambient environment, which is considered as the control condition; (ii) immersion in seawater; and (iii) Tidal zones in the US. The results showed an insignificant variation in the concrete strength among specimens up to 12-month age.

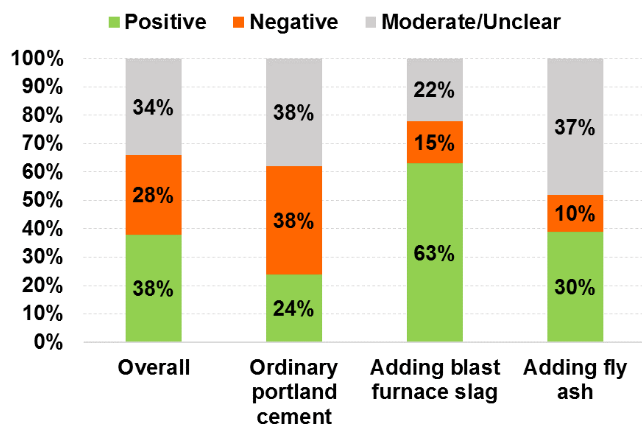

Figure 1. Positive and negative responses for seawater-mixed concrete, using different forms of cement, collected from the previous research.

3 SEAWATER IN REINFORCED CONCRETE

3.1 Corrosion of Steel Reinforcement

Corrosion can be defined as the deterioration of materials, usually metallic, as a result of the reaction with their environment. Steel corrosion is one of the main factors causing the deterioration of RC structures. Several strengthening techniques are proposed in the literature to address this issue and to extend the life of RC structures such as externally bonded fiber reinforced polymers (Ebead 2011, Ebead and Saeed 2014, Elsayed *et al.* 2009, Kotynia *et al.* 2008), Ferro-cement (Ebead 2015), and textile reinforced mortars (Ebead *et al*. 2016, Elghazy *et al*. 2016, Pino *et al.* 2016).

Typically, concrete provides a safe environment for steel, protecting it from corrosion and any other forms of deterioration. However, this protection will dissipate when chlorides are present within the concrete. The critical chloride content (C_{crit}), also referred to as the chloride threshold limit, is defined as the concentration of chlorides that causes the steel to transform from a passive state where no corrosion is occurring, to an active state, where corrosion may begin to occur. Once chloride threshold is reached, as expected in seawater concrete, a flow of electricity occurs from one area of the steel bar (i.e. anode) to another (i.e. cathode) through the bar's surrounding (i.e. electrolyte). This electrochemical reaction results in forming hydroxide ions on the cathode's side of the steel bar, which in turn react with iron to form rust (iron oxide), and hence corrosion initiates. Rusting continues to expand causing severe cracks in the concrete substrate and significant deterioration of reinforcement section (Dyer 2014). C_{crit} is a very important property as it is used in service life modeling to predict the onset of corrosion for applications with external chlorides (Angst *et al.* 2009). Moreover, C_{crit} is used as a basis for codes and specifications to determine the allowable chloride levels at the time of construction.

According to ACI 201.2R-08 Guide for Durable Concrete (2008), a maximum chloride content of 0.20% by cement mass is allowed for reinforced concrete placed in dry or protected environmental conditions. However, for the case of reinforced concrete placed in wet environments, the maximum ratio of the chloride content is 0.1% by cement mass.

3.2 Promising Reinforcement Alternative: Fiber Reinforced Polymer (FRP) Bars

Fiber reinforced polymer (FRP) bars are fabricated from continuous fibers saturated in a polymeric resin matrix via the pultrusion process. The load is carried by the fiber and transferred by the resin. The resin, in turn, protects and binds the fibers together. In the recent years, the application of FRP reinforcement in concrete structures has rapidly increased due to their light weight, high tensile strength, adequate corrosion resistance, and excellent non-magnetization properties (Nanni *et al.* 2014). Concerning mechanical properties, the tensile stress-strain relationship of FRP bars is linear elastic up to failure. FRP bars possess higher tensile strength but lower modulus of elasticity and ultimate tensile strain when compared to steel bars. On the other hand, FRP has some drawbacks such as its sensitivity to abrasion, low modulus of elasticity, and relatively low fatigue resistance (Won *et al.* 2012). Moreover, the mechanical properties of FRP can be affected by exposure conditions such as moisture, acidic or alkaline solutions, salinity, extreme temperature or ultraviolet exposure. Significant research effort has been dedicated in the past few years to provide more understanding about the effect of aggressive environment on the characteristics of FRP bars (Al-Salloum *et al.* 2013, Robert and Benmokrane 2013). Several lab and field applications have also been reported (Aly *et al.* 2006, Moon *et al*. 2009, Zhang *et al*. 2006).

4 FUTURE OUTLOOK

If future building codes and standards were to permit seawater for mixing and curing concrete, we could save critical resources, especially in coastal areas where rapid infrastructure growth and climate aggressiveness are becoming more and more noticeable. From existing literature, the negative effect of using seawater in conventional reinforced concrete appears to be limited to corrosion of steel reinforcement. This issue can be addressed by alternatively using FRP bars to reinforce concrete structures, owing to their ability to resist corrosion. Despite the relatively higher cost of FRP reinforcement compared to black steel, the implementation of life cycle cost analysis of infrastructure projects can result in an overall saving in the long term. Consequently, improving the sustainability of concrete will lead to significant technological and environmental advances, resulting in reducing costs and use of precious resources such as freshwater.

5 CONCLUSION

This paper carried out a short review of previous research work pertinent to the usage of seawater and also FRP reinforcement bars in concrete structures. The following points conclude the effort presented in this paper:

- As postulated in the literature, the effect of seawater on the mechanical properties of plain concrete is insignificant either in the long or in short term.
- Apparently, the key reason for forbidding seawater in ordinary reinforced concrete is the steel corrosion associated with the presence of chloride. Accordingly, contemporary building codes and standards restrict the chloride content in the concrete mixture, commonly by setting maximum limits of the chloride percentage by cement weight.

- FRP reinforcement is strongly recommended in the literature to replace steel in RC structures, due to its adequate and comprehensible mechanical characteristics as well as the corrosion resistance capability.
- Using seawater in association with FRP reinforcement in concrete structures can result in a significant step towards green and sustainable construction worldwide. Further research is required to confirm the safe utilization of such combination (i.e., concrete mixed with seawater and reinforced with FRP bars) in concrete structures.

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